Bureau canadien
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Canadian Aviation
Safety Board

Rapport d'un fait aéronautique civil

Civil Aviation Occurrence Report

Canada

The Canadian Aviation Safety Board investigated this occurrence for the purpose of advancing aviation safety. It is not the object of the Board to determine or apportion blame or liability.

AVIATION OCCURRENCE REPORT

DELTA AIR LINES INC.
BOEING 737-200 N4571M
VANCOUVER INTERNATIONAL AIRPORT
VANCOUVER, BRITISH COLUMBIA
17 JANUARY 1988

REPORT NUMBER 88H0001

SYNOPSIS

The aircraft was on a scheduled flight from Vancouver, British Columbia to Spokane, Washington. During the take-off roll, at between 100 and 110 knots, the flight crew heard a loud bang as the left engine combustion chamber outer case failed. The take-off was rejected, and the aircraft was taxied off the runway. The captain visually confirmed the presence of smoke in the vicinity of the engine after being queried on the matter by air traffic control. An emergency evacuation was then ordered by the captain. Thirty-three passengers and five crew members successfully evacuated the aircraft via the right main exits.

The Canadian Aviation Safety Board determined that the left engine combustion chamber outer casing ruptured as a result of a fatigue-generated crack which originated at a rear flange bolt hole. Crack initiation was most probably a result of the deposit of plating material in the bolt hole during overhaul of the case, contrary to the engine manufacturer's rework instructions. Contributing to the occurrence was the failure of existing inspection procedures to detect the fatigue cracking.

Ce rapport est également disponible en français.

12 December 1989

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1.0 FACTUAL INFORMATION

1.1 History of the Flight

On 17 January 1988, Delta Air Lines Flight 1490, a Boeing 737-200, aircraft registration N4571M, was operating as a scheduled passenger service from Vancouver, British Columbia to Spokane, Washington. Prior to a scheduled 0720 Pacific standard time (PST)* departure, the flight and cabin crew completed their pre-flight duties and checks, with no abnormalities being evident. There were 33 passengers and five crew members on board the aircraft. The captain briefed that the first officer would act as the pilot flying during the flight to Spokane. Before-start checks were completed without incident. Delta Flight 1490 received its instrument flight rules (IFR)** clearance to Spokane, and, at 0718 PST, the aircraft was instructed to taxi to runway 08 and to await take-off clearance. At 0728 PST, Delta Flight 1490 was cleared to take off and to contact Departure Control after take-off. Delta Flight 1490 acknowledged the clearance. The initial take-off roll was uneventful until the airspeed reached between 100 and 110 knots***. At that time, the flight crew heard a loud bang, and the aircraft veered slightly to the left. The take-off was rejected, and the aircraft was brought to taxiing speed as it approached taxiway Whiskey. At approximately this time, air traffic control (ATC) personnel queried Delta Flight 1490 about the presence of smoke on the left side of the aircraft. The lead purser entered the flight deck and asked if it was a tire. After confirming with the captain that the left engine had failed, the first officer shut down the engine and activated the left engine fire extinguisher system. The aircraft was taxied off the 200-foot-wide runway onto taxiway Whiskey, which is 75 feet wide, where it was brought to an immediate stop.

After the aircraft came to a stop, the captain opened the left direct vision window and confirmed the presence of significant amounts of smoke surrounding the left engine. The captain was advised by ATC that Crash, Firefighting and Rescue (CFR) vehicles were on

* All times are PST (Coordinated Universal Time (UTC) minus eight hours) unless otherwise stated.
** See Glossary for all abbreviations and acronyms.
*** Units are consistent with official manuals, documents, reports, and instructions used by or issued to the crew.

the way. He then ordered an emergency evacuation on the right side of the aircraft. The two right main exit doors were opened, and the escape slides deployed. The flight attendants directed the passengers to both exits, and the evacuation was completed without injury, except for one passenger receiving a minor abrasion of an elbow and another a superficial cut on a finger. Neither required hospitalization. The pilots secured the aircraft and then evacuated via the front right exit. CFR personnel extinguished a small fire contained in the left engine exhaust and then cooled down the engine using water and foam.

Passengers and crew were transported to the airport terminal building.

The occurrence took place on airport property at lat 49°11'N, long 123°11'W at a reference elevation of nine feet above sea level, at 0728 PST during the hours of daylight.

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	-	-	-	-
Serious	-	-	-	-
Minor/None	5	33	-	38
Total	5	33	-	38

1.3 Damage to Aircraft

The left engine combustion chamber outer case (CCOC) ruptured, and portions of the CCOC exited the left engine, severing hydraulic and electrical lines and fittings. In turn, engine debris pierced the engine cowling at the three o'clock position, aft looking forward, and struck the lower surface of the wing, the leading edge of a section of trailing edge flap, as well as the left main landing gear assembly. Damage to the aircraft structure was superficial, with the exception of cuts to one main landing gear tire and one gouge on the lower surface of the wing.

1.4 Other Damage

There was no other damage.

1.5 Personnel Information

1.5.1 Pilots

	Captain	First Officer
Age	52	39
Pilot Licence	Airline Transport (U.S.A.)	Airline Transport (U.S.A.)
Medical Expiry Date	29 Feb 1988	30 May 1988
Total Flying Time	15,400 hr	4,000 hr
Total on Type	820 hr	420 hr
Total Last 90 Days	210 hr	140 hr
Total on Type Last 90 Days	210 hr	140 hr
Hours on Duty Prior to Occurrence	1 hr	1 hr
Hours off Duty Prior to Work Period	19 hr	18 hr

Both pilots were qualified and licensed to fly the B737 aircraft. Both pilots held current medical certificates: the Captain's certificate had no limitations; the first officer was required to wear glasses while performing the duties of a flight crew member.

1.5.2 Cabin Crew

The cabin crew comprised a lead purser and two flight attendants. The cabin crew were medically fit and qualified for their duties. All had received the off-duty times prescribed by regulations.

1.6 Aircraft Information

Manufacturer	Boeing Commercial Aircraft Co. U.S.A.
Type	Boeing 737-200
Year of Manufacture	1983
Serial Number	22793
Certificate of Airworthiness	Valid
Total Airframe Time	12,757 hr
Engine Type (2)	Pratt & Whitney JT8D-17
Maximum Allowable Take-off Weight	121,500 lb
Recommended Fuel Types	Jet A, Jet B

The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

The weight and centre of gravity were within the prescribed limits.

1.6.1 Combustion Chamber Outer Case History

The CCOC, serial number 4642, was installed in Pratt & Whitney (P&W) JT8D-17 engine, serial number 708823. At the time of the occurrence, the CCOC had accumulated 44,935.17 hours time since new (TSN) and 38,080 cycles since new (CSN). See Appendix B for service history and applicable overhaul record of the CCOC.

On 11 January 1987, 1,751 cycles prior to rupture, an off-wing inspection of the engine was performed, including a fluorescent penetrant inspection (FPI) of the CCOC for cracks. This CCOC inspection was carried out in accordance with Federal Aviation Administration (FAA) Airworthiness Directive (AD) 86-04-01 and P&W Alert Service Bulletin (ASB) 5676, and no cracks were reported as being evident.

An on-wing inspection of the CCOC, using mirror and light, had been completed on 06 October 1987, 656 cycles prior to rupture, and no cracking was reported as being evident at that time.

1.7 Meteorological Information

The Vancouver weather at 0700 PST was reported as sky condition 1,500 feet scattered, 3,500 feet scattered, 9,000 feet thin broken; visibility 15 miles; temperature two degrees Celsius, dew point one degree Celsius; wind 050 degrees magnetic at four knots; and altimeter setting 29.85 inches of mercury. Just prior to starting the take-off roll, the first officer noted that rain had begun to fall.

1.8 Aids to Navigation

All relevant navigational equipment, both on the aircraft and operated by air traffic services (ATS), operated normally.

1.9 Communications

1.9.1 ATS - Flight Crew Communications

At the time of the occurrence, Delta Flight 1490 was transmitting and receiving on Vancouver Tower frequency. At 0728:31 PST, 10 seconds after initiating a rejected take-off, Delta Flight 1490 advised Vancouver Tower that it was rejecting the take-off on the runway. At 0728:44 PST, Vancouver Tower responded with "Delta 1490 does there appear to be flames in your left engine?" The aircraft called clear of the runway on taxiway Whiskey at 0729:05 and again at 0729:34 PST. The captain advised Vancouver Ground at 0730:07 PST that an evacuation would be carried out on the right-hand side.

1.9.2 ATS - Airport Emergency Services Communications

ATS attempted to telephone the Airport Emergency Service (AES) when Delta Flight 1490 rejected its take-off and smoke was observed in the vicinity of the left engine. The telephone call was not immediately answered, so ATS personnel activated the crash bell and established radio contact on ground control very high frequency (VHF) with the CFR vehicles as they left the firehall. Communication between CFR vehicles and ATS was subsequently transferred to a discrete ultra-high frequency (UHF) to keep the ground control frequency clear for normal traffic.

1.9.3 Flight Crew Communications

The flight crew intercommunication and VHF radio communication systems operated properly from the commencement of pre-flight checks until the aircraft was shut down during the emergency evacuation.

1.9.4 Flight Crew - Cabin Crew Communications

The flight deck access door was closed before the passengers boarded the aircraft. The first officer made a cabin public address announcement just before take-off, advising passengers that Delta Flight 1490 was number one for take-off and asked the flight attendants to be seated. After the engine failure, the head purser, seated at the left forward main exit, got up and knocked on the flight deck access door, entered the flight deck and said "tire?" The first officer replied "I don't know", and the captain stated "I think it's an engine." The captain then gave the command to evacuate to the first officer and the lead flight

attendant. The lead flight attendant returned to the passenger compartment and told the two other flight attendants that an evacuation was necessary and to use the right-side door exits. The lead and number two flight attendants then directed passengers to evacuate the aircraft through the closest exits.

1.10 Aerodrome Information

Vancouver International Airport is licensed as a public airport and is operated by Transport Canada. It is located on the Strait of Georgia shoreline southwest of the city of Vancouver and has a reference altitude of nine feet above sea level. The asphalt runway in use was runway 08, which is 11,000 feet long by 200 feet wide. The accelerate stop distance available (ASDA) is also 11,000 feet. Taxiway Whiskey intersects runway 08 5,906 feet from its beginning. The runway condition was reported as bare and dry at the time of the occurrence.

1.11 Flight Recorders

The cockpit voice recorder (CVR) and flight data recorder (FDR) were removed from the aircraft after the occurrence and transported to the National Research Council Flight Recorder Playback Centre (FRPC) for analysis.

1.11.1 Cockpit Voice Recorder

The aircraft was equipped with a Fairchild A100 CVR, serial number 1690. The FRPC recovered a complete four channel recording of the pilot and co-pilot's interphone and radio reception transmission as well as the cockpit area microphone from approximately 28 minutes prior to the engine failure up to the point when electrical power was cut to the CVR during aircraft shutdown and passenger emergency evacuation.

1.11.2 Flight Data Recorder

The aircraft was equipped with a Sundstrand Universal FDR, serial number 736. The FDR was capable of recording on 68 parameters, 42 of which were discrete (ON/OFF) recorded information.

The FDR data did not indicate any engine abnormality prior to the CCOC rupture.

1.12 Wreckage and Impact Information

The aircraft stopped on taxiway Whiskey, at the intersection of the taxiway and runway 08, approximately 6,000 feet from the starting point of the take-off roll. Debris from the ruptured CCOC, hydraulic lines, and fittings exited the engine radially. Some of the debris struck the aircraft left wing lower surface, gouging the wing surface to a depth of 0.053 inches at a position 37 inches inboard of the engine pylon and 11 inches forward of the rear spar. The left main landing gear door as well as the outboard wheel cover and tire were also struck by debris, resulting in superficial damage and tire cuts. The leading edge of the inboard section of the trailing edge flap was dented by a piece of unidentified debris. Debris from the failed engine was scattered on runway 08 in the vicinity of taxiway Bravo, approximately 2,000 feet from the beginning of runway 08.

The left engine was not damaged by fire, nor was there apparent evidence of engine damage other than in the immediate area of the CCOC.

1.12.1 Left Engine Examination

Portions of the CCOC, incorporating the mating fracture faces of the rupture, were cut from the case and forwarded to the CASB Engineering Laboratory. The left engine was then taken to Delta Airlines Inc. maintenance facility in Atlanta, Georgia under the direct supervision of the CASB. A detailed disassembly and examination were carried out in the presence of CASB personnel. This examination did not reveal any discrepancies with the engine.

1.12.2 Left Engine CCOC Examination

The left engine CCOC was initially examined on 25 January 1988 at the CASB Engineering Laboratory in the presence of representatives of the National Transportation Safety Board (NTSB), the FAA, Pratt & Whitney Aircraft Group, and Transport Canada. The examination showed pre-existing cracking in numerous locations other than the primary rupture through bolt hole number 24. The combustion case fracture appeared discoloured in the area of the rear flange. The crack at bolt hole number 30 was opened in the presence of the above parties, and fatigue cracking was evident.

Cracking was also found at bolt hole numbers 20, 26, 27, 28, 29, and 31. Hardness testing of the CCOC indicated a below-specification hardness condition in various locations as follows:

Hole Number	Mean Hardness - HRC*
1	26.4
15	25.1
25	25.3
31	26.1
37	25.4
48	25.5
60	24.1
75	25.8

* Hardness Rockwell "C"

Pratt & Whitney engineering drawings of the CCOC call for a hardness condition between 30.0 and 38.0 HRC. Subsequently, a detailed examination and analysis of the case fracture was undertaken by the CASB Engineering Laboratory. The report of this examination and analysis documents numerous bolt hole cracks in addition to the primary fracture. Metallographic analysis did not identify any material faults; however, hardness measurements confirmed the values listed above and showed the material to be significantly below the engineering drawing requirement. Several anomalies in the finish of the case inner diameter surface were noted, but these appeared to be unrelated to the cracking. The presence of thick layers of nickel-cadmium in CCOC rear flange bolt holes was also noted. The development of cracks originated in the nickel-cadmium plating material and then extended into the substrate. The Pratt & Whitney JT8 Engine Manual contains a caution in Chapter 72-41-11 Repair 08, page 905, as follows:

> CADMIUM PLATE IS NOT ALLOWED IN HOLES OF FRONT OR REAR FLANGE OR HOLES IN ANY OTHER AREA. ANY CADMIUM PLATE IN ANY HOLE MUST BE REMOVED.

The length of the progressive section of the primary crack was measured at 5.15 inches (13.08 cm). Surface contamination precluded any determination of growth rate; however, fractographic analysis of two much shorter secondary cracks produced an estimated crack development time in the range of 7,000 to 8,000 cycles.

Pratt & Whitney examined sections of the CCOC rear flange fracture surfaces and produced a metallurgical report on their findings. The Pratt & Whitney report reached similar conclusions to the CASB findings regarding mode of failure, cycle count, and the reason for crack initiation. The report also notes a finding of nickel, cadmium, aluminum, and silicon on the fracture surface. Hardness readings for the CCOC were found to be higher than those of the CASB; however, a re-evaluation confirmed the validity of the CASB figures.

1.13 Medical Information

There was no evidence that incapacitation, physiological, or psychological factors affected the flight or cabin crew's performance.

1.14 Fire

Fire resulting from pooled jet fuel was contained within the left engine exhaust section. Hydraulic fluid from severed hydraulic lines sprayed on the hot engine exhaust section and caused several small spot fires that flared sporadically after the engine was shut down.

CFR vehicles were on the scene within two minutes. Passengers and crew were evacuating the aircraft as CFR personnel extinguished the exhaust section fire using hand-held HALON extinguishers. Water and foam were applied to the left engine exhaust section to cool it down and put out the spot fires. Hydraulic fluid on the taxiway from the failed engine was also sprayed with water and foam. CFR personnel were not required to assist in the passenger evacuation.

1.15 Survival Aspects

The aircraft fuselage was not damaged by uncontained engine debris nor by fire. This was a survivable occurrence.

1.16 Tests and Research

Nil.

1.17 Additional Information

1.17.1 CCOC Fatigue-Cracking Visual Inspection Procedures

A number of CCOC fatigue-cracking inspection procedures had been developed by operators and the engine manufacturer to better ensure that fatigue cracking was discovered before it progressed to a critical dimension. One on-wing inspection procedure, known as the mirror and light method, requires the technician to enter the engine exhaust section and visually inspect the outer diameter of the rear flange of the CCOC by manipulation of a white light source and a mirror. A borescope inspection procedure achieves the same purpose; however, engine panels adjacent to the CCOC have to be removed so that the borescope can be inserted in inspection ports around the CCOC. Neither of these visual inspection procedures is capable of detecting cracks originating on the inner diameter face of the CCOC.

The engine manufacturer recognized that certain cracks might not be detected using either of these methods. Pratt & Whitney risk analysis of the matter determined that a 1/32-inch crack could be missed during a visual on-wing inspection but predicted crack propagation rates would not result in a fatigue crack-related rupture prior to the next off-wing inspection using the more accurate and reliable FPI or fluorescent magnetic particle inspection (FMPI) procedures.

1.17.2 Previous CCOC Failures

On 19 October 1985, a McDonnell-Douglas DC-9-51, registration N412EA, operating as Eastern Airlines Flight 250, experienced a left engine failure just after take-off from Tampa, Florida. The aircraft returned to Tampa without further incident. Subsequent investigation revealed that the left engine CCOC had ruptured from its rear flange toward the forward flange at the three o'clock position, aft looking forward. Portions of the ruptured CCOC plus adjacent components exited the engine; however, the aircraft was not significantly damaged by this debris.

Examination of the ruptured CCOC revealed that low-cycle fatigue had initiated at bolt hole number 25 and progressed radially through the rear flange and axially through the case skin for approximately 4 1/2 inches at the three o'clock position. There was no evidence of pre-existing thermal distress. There was evidence of nickel cadmium on the initial 0.25 inches of the fatigue surfaces as well as on the surface of

bolt holes in the rear flange. Additional radial fatigue cracks, up to 1/16 of an inch in length, were also noted at two bolt holes adjacent to the fracture.

On 22 August 1985, the left engine of a Boeing 737-200, registration G-GBJL, operated by British Airtours, failed during take-off from Manchester International Airport, Manchester, England. The take-off was rejected; however, the entire aft portion of the aircraft was engulfed in fire shortly after the aircraft came to a stop. Fifty-four of the 137 persons on board the aircraft were fatally injured before the fire was extinguished. The post-accident inspection revealed that the CCOC had ruptured as a result of failure of one of the engine's nine combustion chambers. The combustion chamber failure allowed hot combustion air to impinge on and burn the wall of the outer case to the point where it was not capable of containing the burner compartment air, and it ruptured.

Both of these instances of CCOC rupture resulted in uncontained engine failure.

1.17.3 National Transportation Safety Board Recommendation - CCOC Fatigue-Cracking Inspection Procedures

As a result of the above-noted two occurrences, as well as previously detected and reported instances of CCOC fatigue cracking, the NTSB issued Recommendation A-85-141 to the FAA stating that:

> The engine manufacturer and JT8D operators (1) develop and implement inspection procedures which ensure early detection of outer combustion case cracking and evidence of high temperature burner air impingement on the combustion case wall, and (2) specify the criteria and procedure for repair of detected fatigue or overheat damage.

Subsequent to this recommendation, the FAA issued AD 86-04-01, which was superseded by AD 87-11-07. These AD's specified minimum inspection limits and methods based on cycles since new and since last inspection for CCOCs of various models of JT8D engines.

After the issuance of AD 86-04-01 and 87-11-07, the NTSB in expressing its concern to the FAA stated, among other things, that the use of the mirror and light on-wing inspection method for other than the initial,

or drawdown, inspection should only be considered as an interim measure. The NTSB also stated that a more positive and reliable inspection procedure should be developed, using available state-of-the-art techniques to detect cracks while they are still in their embryonic stage rather than after the cracks have propagated through the rear flange and are approaching critical length. Finally, the NTSB stated its belief that an eddy current method of inspection developed by the manufacturer, Pratt & Whitney, offered a significant safety advantage over the mirror and light method in that it can detect cracks in the CCOC rear flange before they propagate beyond the flange and axially into areas adjacent to the CCOC.

1.17.4 Revised CCOC Fatigue-Cracking Inspection Procedures

CASB staff met with Pratt & Whitney representatives and a Federal Aviation Administration (FAA) official subsequent to this occurrence and after Pratt & Whitney had completed their metallurgical report. The engine manufacturer displayed a recently developed apparatus that allows operators to conduct on-wing eddy current inspections of the CCOC rear flange, thereby eliminating the need for mirror and light inspections. Over 200 of these apparatus have been produced by Pratt & Whitney and have been distributed to operators. In addition, Pratt & Whitney discussed current and proposed inspection requirements for the CCOC, both in-shop and on-wing. Their proposal was to change the in-shop inspection procedure from FPI to FMPI. The FAA representative stated that the FAA was in general agreement with Pratt & Whitney's proposal and was moving in that direction.

2.0 ANALYSIS

2.1 Combustion Chamber Outer Casing Failure

Initial examination of the left engine at the occurrence site indicated that an uncontained rupture of the CCOC initiated the engine failure. Subsequent examination of the combustion chamber outer case and the fractographic analysis of secondary cracks determined that rupture of the case was preceded by a fatigue-generated crack which originated at a bolt hole in the rear flange. This crack progressed forward through the sidewall until the integrity of the case was reduced to the point where rupture occurred as a result of the normal high internal pressure generated in the engine during take-off. Based on striation counts in regions of the secondary cracks, it is believed that the primary crack, as well as others, existed at the time of the on-wing inspection, 656 cycles prior to the CCOC failure; at the time of the most recent shop inspection of the case, 1,751 cycles before the occurrence; and, most probably, at the time of the next-to-last shop inspection in October 1984.

2.2 CCOC Crack Initiation

The historical record of the CCOC indicated that the CCOC was in service for considerable time before cracking commenced. It is most probable that the nickel-cadmium deposit in the bolt holes occurred when a plating process was performed during rework of the case, rather than at the time of manufacture. As noted by the engine manufacturer in its metallurgical report, this rework appeared to coincide with a repair of the flange by application of nickel plate and reapplication of the nickel-cadmium protective coating. It is also probable that the reduction in hardness of the case material was the result of a rework process rather than some in-service flame pattern irregularity or overtemperature condition which would be evidenced by more localized changes in hardness. It was not possible to conclude whether both faults were introduced at the same time, nor when or by whom the relevant rework was performed. Pratt & Whitney's metallurgical report noted the presence of nickel, cadmium, aluminum, and silicon on the fracture surface, indicating that the crack was present at the time of the last application of either Sermetal W coating or aluminum paint.

Thus, there are insufficient data available to make a definitive determination of the cause of crack initiation. There is a confirmed correlation between the plating deposit in the bolt holes and cracking; however, what is not known is whether the reduced material hardness significantly contributed to the process in this instance. The previously mentioned NTSB report of a similar CCOC rear flange crack and failure stated that the material of that case was well above the minimum requirement, thereby downplaying the involvement of the hardness factor.

2.3 Engine Rework Procedures

The presence of nickel-cadmium plating in the CCOC rear flange bolt holes and its direct link to the most probable cause of cracking resulted in a close examination of engine rework instructions. The inclusion of a specific caution in repair instructions that cadmium plate is not allowed in any CCOC holes and that any cadmium plate in any hole is to be removed would appear to be sufficiently clear as to intent.

2.4 CCOC Crack Inspection Procedures

The occurrence CCOC underwent one on-wing mirror and light inspection and at least one (most probably two) off-wing inspection using FPI, and, although cracks existed, they were not detected using these inspection methods. Deficiencies in the mirror and light inspection method have been previously identified by the NTSB. Concerns centered upon the reliance on a technician being able to see cracks when operating in a very confined and dark area and the inability of the inspection procedure to detect cracks until they had progressed to the outer diameter of the CCOC. The apparant inability of the off-wing FPI inspection method to detect the cracks in the occurrence CCOC is also of concern.

2.5 Engine Maintenance and Overhaul Quality Assurance

The occurrence CCOC had previously undergone maintenance and overhaul work at FAA-approved facilities and ostensibly in accordance with the manufacturer's procedures. Notwithstanding these facts, the CCOC exhibited below-specification hardness and nickel-cadmium in rear flange bolt holes, contrary to manufacturer instructions. In addition, fatigue-related cracking was not detected during two, and perhaps more, inspections. Applicable maintenance

and overhaul instructions were reviewed, and there was no indication that further amplification or clarification of procedures is required. It appears that there have been instances where instructions have not been followed due to simple human error.

Quality assurance procedures are in place at all approved maintenance and overhaul facilities. These procedures are designed to lessen the possibility of human error; however, the monitoring procedures must be stringent in processes where non-compliance with instructions could result in an engine failure.

2.6 Flight Crew Rejected Take-Off Procedure

The flight crew involved in this occurrence responded rapidly and correctly to the engine failure during the take-off run, prior to the decision speed being reached. The captain's decision to taxi the aircraft off the runway onto a taxiway was not the result of a deliberate decision-making process. Rather, it was the result of seeing the taxiway to his left as the aircraft was decelerated to taxi speed and turning the aircraft off the runway for some or all of the reasons cited below. In this occurrence, taxiing the aircraft off the runway did not result in any increase in danger to the aircraft occupants or the aircraft itself. The absence of a significant fire that could threaten the aircraft fuselage meant that wind direction and the narrower paved manoeuvring area of the taxiway on which the CFR vehicles had to operate were not factors in the survivability of this accident.

Rejected take-off procedures for large transport-category aircraft are universal in their requirement for flight crews to stop aircraft straight ahead on the runway before determining the source of the emergency and whether the aircraft can be taxiied clear of the runway. The decision about whether a rejected take-off should be carried out must be made quickly, and the procedure must be completed without reference to a check-list. To better ensure that flight crews have complete recall of the procedure, many operators require their flight crews to verbally recall the rejected take-off procedure as part of the take-off and departure briefing, or alternatively as part of a first flight of the day recall of memory-item emergency procedures.

Despite this reinforcement of the rejected take-off procedure, flight crews in general are reluctant to stop an aircraft on a runway after a rejected take-off. When questioned on the matter, pilots will express a desire to clear the runway so that other aircraft can take off and land. This desire to clear the runway has been instilled in pilots from their first flight. Good airmanship and consideration for other aircraft has meant that an aircraft remains on the runway for the minimum time necessary.

This strong desire carries over to the rejected take-off procedure and results in aircraft and those onboard potentially being put at greater risk. This increase in risk can be caused by a number of factors, including the delay in finally stopping the aircraft so that an emergency evacuation can be carried out. Moving an aircraft from a 200-foot-wide runway to a 75-foot-wide taxiway reduces the prepared manoeuvring area upon which Crash, Firefighting and Rescue equipment can operate and thus increases the difficulty in knocking down a fire and establishing evacuation routes for aircraft occupants.

3.0 CONCLUSIONS

3.1 Findings

1. During the take-off roll, the left engine combustion chamber outer casing ruptured as a result of a fatigue-generated crack which originated at a rear flange bolt hole.

2. Fatigue-generated cracking was present in the rear flange of the case during an on-wing fatigue crack inspection of the case, 656 cycles prior to rupture and during an off-wing shop inspection of the case, 1,751 cycles prior to rupture.

3. Crack initiation was most probably a result of the deposit of nickel-cadmium plating material in the bolt hole during overhaul of the case.

4. The hardness of the combustion chamber outer case material was found to be below specification.

5. The rupture of the combustion chamber outer casing resulted in an uncontained engine failure.

6. Debris from the uncontained engine failure caused superficial damage to the left main landing gear and the underside of the left wing.

7. The flight crew rejected the take-off after hearing the case rupture.

8. The aircraft was taxied off the runway prior to being stopped.

9. After confirming ATC reports of smoke in the left engine, an emergency evacuation was carried out.

10. All 33 passengers and five crew members successfuly evacuated the aircraft.

11. Crash, Firefighting and Rescue services arrived at the aircraft as passengers were evacuating the aircraft and were required to put out spot hydraulic fluid-fed fires.

12. The flight crew was certified and qualified for the flight in accordance with existing regulations.

13. The aircraft was certified and maintained in accordance with existing regulations.

14. The take-off weight and centre of gravity position were within the prescribed limits.

3.2 Causes

The Canadian Aviation Safety Board determined that the left engine combustion chamber outer casing ruptured as a result a fatigue-generated crack which originated at a rear flange bolt hole. Crack initiation was most probably a result of the deposit of plating material in the bolt hole during overhaul of the case, contrary to the engine manufacturer's rework instruction. Contributing to the occurrence was the failure of existing inspection procedures to detect the fatigue cracking.

4.0 SAFETY ACTION

4.1 Action Taken

4.1.1 Revised Inspection Procedures

As a result of the uncontained failures of JT8D engines in August 1985 at Manchester, England and in October 1985 at Tampa, U.S.A. and other instances of reported fatigue cracking, the FAA issued Airworthiness Directives AD 86-04-01 and AD 87-11-07 which specified minimum inspection intervals based on cycles since new and since the last inspection for combustion chamber outer casings (CCOC).

In view of this occurrence at Vancouver and the continued concern of the NTSB, the engine manufacturer developed an apparatus that allows an on-wing eddy current inspection of the CCOC. In addition, the off-wing inspection procedure was changed from a fluorescent particle inspection to a fluorescent magnetic particle inspection (FMPI). These revisions were intended to reduce the likelihood of a fatigue crack remaining undetected during inspections. The revised inspection procedures were issued by the manufacturer in December 1988 as an amendment to Alert Service Bulletin 5676. Operators were notified of the revision and the availability of the eddy current apparatus through an All Operators letter.

On 01 March 1989, the FAA issued a telegraphic Airworthiness Directive (T89-05-52). This AD replaced the eddy current and FMPI inspections with an ultrasound technique.

4.2 Action Required

4.2.1 Emergencies On Runways

As a consequence of an uncontained engine failure and the resultant fuel-fed fire during a rejected take-off at Calgary in 1984 (Report No. 84-H40003), the CASB recommended that:

> The Department of Transport require that aircraft-on-the-ground emergency procedures and training emphasize the need to stop an aircraft immediately and determine the nature of the emergency.

CASB 87-03

In response; Transport Canada sent a letter to air carriers in November 1987, emphasizing the need to confirm the nature of an emergency before moving the aircraft. Since then, new information regarding the characteristics of fuel-fed fires and crash fire rescue equipment has come to light. Because this information bears on the decisions required of crews involved in rejected take-offs, the issue should be reviewed.

Subsequent to a rejected take-off and fuel-fed fire at Manchester, U.K. in November 1985, the Accident Investigation Branch of the U.K. made several findings regarding the fire's behaviour. The source of the fire was fuel from a ruptured fuel tank in the left wing, and the aircraft had been taxied onto a taxiway to the right of the runway after the rejected take-off. Because the light wind carried the flames against the fuselage, the fire penetrated the fuselage into the cargo hold in 40 seconds, the cabin windows in 40 to 50 seconds, and the cabin wall in about 60 seconds. The report concluded that the wind, although light, was the principal factor controlling the fire's progress: "... a slight wind (2 kt or more), of little or no operational significance from an aircraft handling and performance standpoint, is nevertheless critically important so far as aircraft orientation in a fire is concerned."

The capability of Crash Fire Rescue (CFR) vehicles to operate off prepared surfaces has been a significant factor in previous accidents. Therefore, Transport Canada commissioned a study by SAGE Consultants into CFR services. This study concluded (inter alia) that the performance of CFR vehicles on unprepared surfaces could not be significantly improved in the near future due to limits imposed by technology. Therefore, instead of clearing the runway for other traffic, pilots of distressed aircraft must consider remaining on the runway which has a larger prepared surface for CFR vehicles.

Rejected take-off procedures for large transport-category aircraft are universal in their requirement for pilots to stop the aircraft straight ahead on the runway and assess the emergency to determine whether to taxi clear. In cases involving fire, knowledge of its location and of the wind direction are critical and must be determined immediately, and considered in the decision whether or not to taxi. Preparation for this important decision should include a pre-flight knowledge of infield condition and a wind check before brake release. In

cases where an evacuation is necessary and aircraft orientation is not ideal, the time required to re-orient the aircraft must be weighed against the additional risk imposed by the delay.

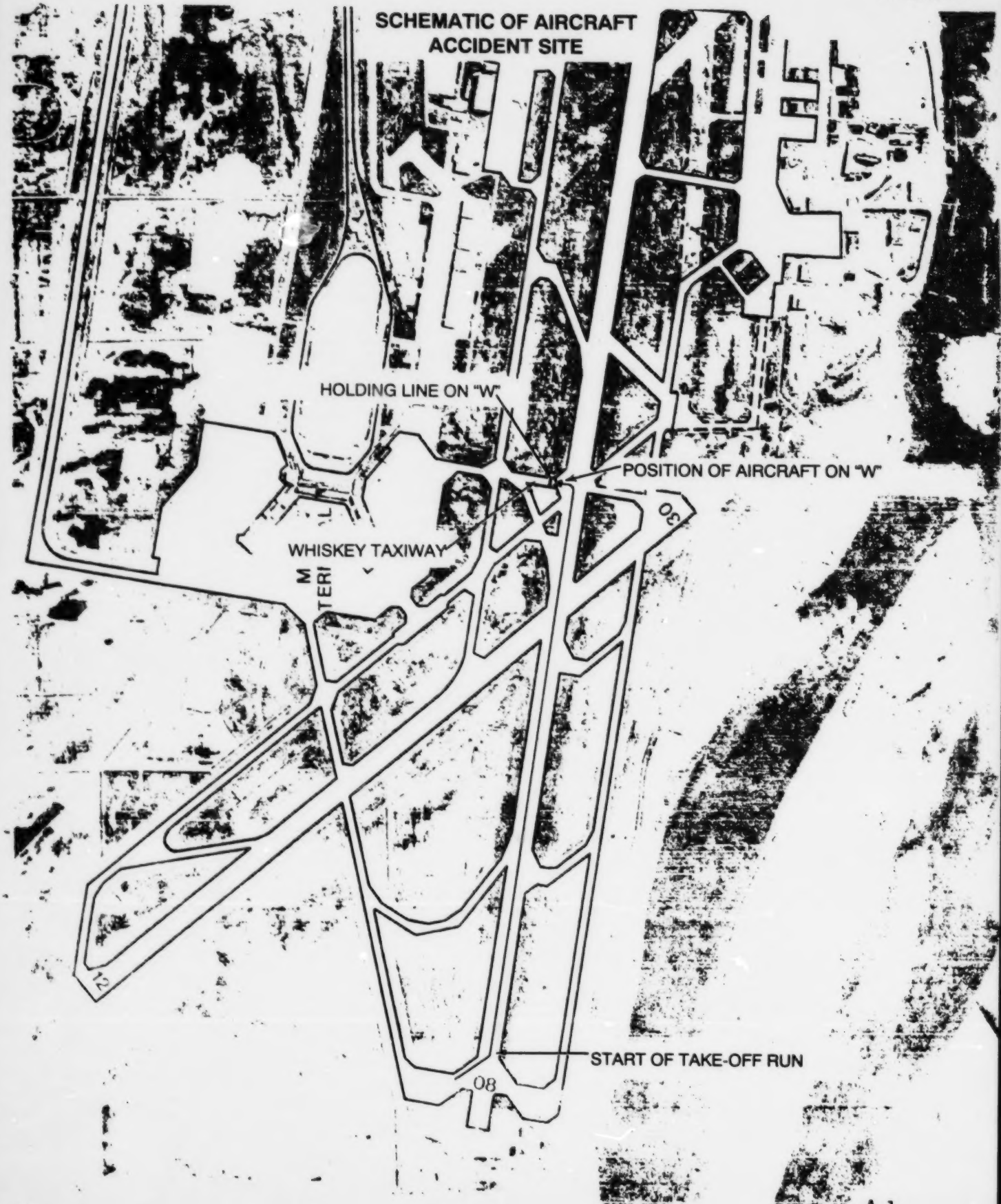
The Board believes that passengers of transport aircraft could be exposed to unnecessary risk during on-runway emergencies if flight crews do not fully assess the extent of the emergency and consider external conditions such as wind and airfield surface conditions before taxiing clear of the runway. Therefore the CASB recommends that:

> The Department of Transport issue a safety bulletin explaining to the flight crews of transport aircraft the reasons for stopping the aircraft on the runway during aircraft-on-the-ground emergencies before deciding whether to taxi clear.

CASB 89-10

This report and the safety action therein has been adopted by the Chairman, K.J. Thorneycroft, and Board Members:

N. Bobbitt
W. MacEachern
A. Portelance
B. Pultz
F. Thurston

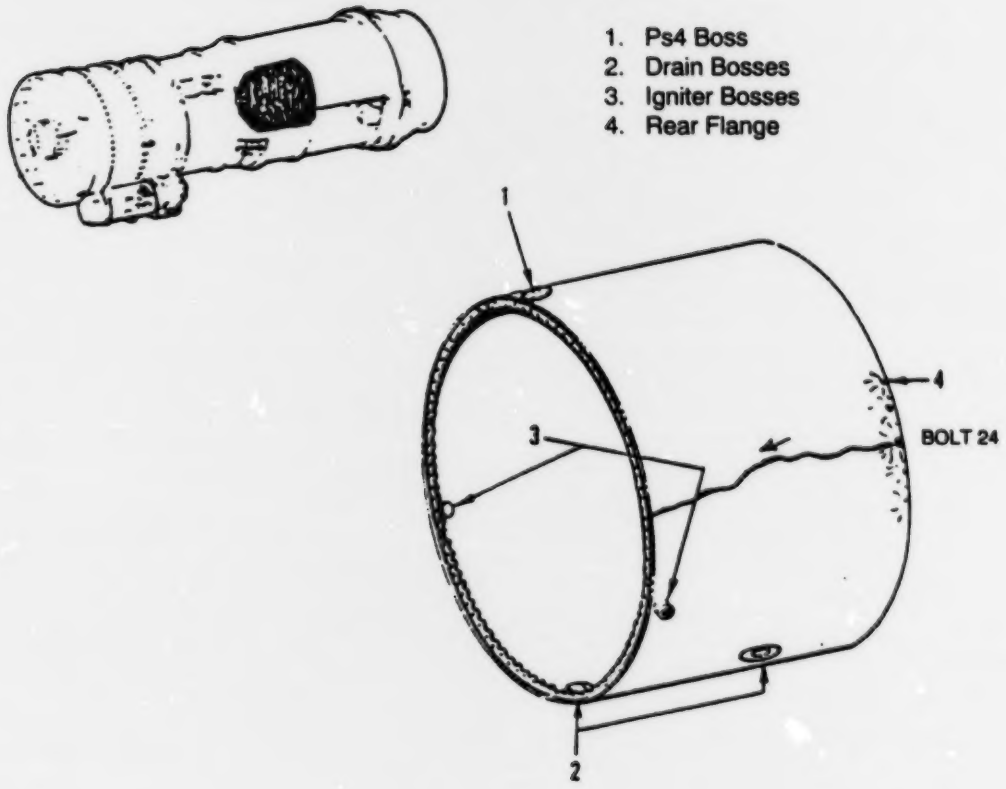

SCHEMATIC OF AIRCRAFT ACCIDENT SITE
HOLDING LINE ON "W"
POSITION OF AIRCRAFT ON "W"
WHISKEY TAXIWAY
30
12
08
START OF TAKE-OFF RUN

COMBUSTION CHAMBER OUTER CASE SERIAL NUMBER 4642/464

SERVICE HISTORY

Date	Event
12 May 1969	Case delivered by Pratt & Whitney Inc. to Western Airlines (WAL) as an original component of JT8D-9 Engine Serial No. 674315.
16 December 1972	Engine 674315 removed for Shop Major Visit (SMV) because of high oil consumption. Case identified as Part No. 542155 Serial No. 4642 was inspected in accordance with WAL inspection sheets. No details of inspection method or findings recorded. Total Time (TT) 7,035:43. Total Cycles (TC) 9,078.
27 January 1973	Case reinstalled in Engine 674315 and returned to service.
11 September 1975	Engine 674315 removed for SMV because of time. TT - 13,019:18. TC - 16,348. Case had same life as engine at time of this removal. Case was reworked by installation of PS4 boss and reidentified as Part No. 616315. WAL Work Order 2373 lists the procedure. Serial number of case changes in records at this time from 4642 to 464, probably as a result of a clerical error.
20 February 1976	Case installed in engine Serial No. 674301, at this time, the engine was being converted from JT8D-9 to JT8D-15. (Engine TT - 12,552:11 TC - 12,992)
11 November 1978	Engine 674301 SMV for disc cycles. No information regarding inspection of case. Returned to service 02 Mar 1979.
14 December 1979	Engine 674301 removed for repair of foreign object damage (FOD). Returned to service 13 Feb 1980.
14 October 1981	Engine 674301 removed for repair of exit case damage. Returned to service 22 Oct 1981.

05 July 1982	Engine 674301 removed for FOD repair. Combustion chamber outer case was inspected (Zyglo) and declared serviceable on WAL Work Order 4362.
04 October 1984	Engine 674301 removed for disc time/cycles. Case inspection was recorded on WAL Shop Order S/N 521749. The form lists "Reason for Removal" as "Cracked" but no details are provided. Engine TT - 36,069:33 TC- 28,994. (Case time/cycles calculated by subtracting engine times when case installed in Feb 76 and adding time from previous installation) Case TT - 36,536:40 TC - 32,350. Returned to service in same engine on 08 Feb 1985.
11 January 1987	Engine 674301 removed for hours/cycles. Engine TT -42,347:23 TC - 32,973. Case TT now 42,814:30 and TC - 36,329. Case was inspected on WAL Shop Order S/N 574493. Following inspection, case was installed in Engine Serial No. 708823. Engine TT - 10,080:19 TC - 10,541. Returned to service 04 Apr 1987.
06 October 1987	Special inspection of combustion chamber outer case performed (on-wing inspection) Reference Job Card 5012 Card No. 71. Documentation of time/cycles was not available, but verbal information is that engine TC on date was 11,636 or 656 cycles prior to the failure. Card is initialled to indicate inspection was performed, but condition was not specified. Form does not include block to list findings.
17 January 1988	Uncontained rupture of combustion chamber outer case of Engine 708823. Engine TT - 12,201:06 TC - 12,292. Time/cycles for case during this installation and since last SMV was 2,120:47 hours and 1,751 cycles. Case TT - 44,935:17 TC - 38,080.



LOCATION AND PROGRESSION OF THE CRACK ON THE COMBUSTION CHAMBER OUTER CASE

LIST OF ENGINEERING REPORTS AND ENGINE INSPECTION PROCEDURES

The following engineering reports and revisions to relevant engine inspection procedures were completed:

CASB LP 9/88 - Engine Failure Analysis

Pratt & Whitney Metallurgical Report on Combustion Chamber Outer Case Part Number 616315, Serial Number 4642

Pratt & Whitney JT8D Outer Combustion Chamber Case Rear Flange OD Eddy Current Inspection (Installed)

These reports are available upon request from the Canadian Aviation Safety Board.

GLOSSARY

AD	Airworthiness Directive
AES	Airport Emergency Services
ASB	Alert Service Bulletin
ASDA	accelerate stop distance available
ATC	air traffic control
ATS	air traffic services
CCOC	combustion chamber outer case
CFR	Crash Firefighting and Rescue
CSN	cycles since new
CVR	cockpit voice recorder
FAA	Federal Aviation Administration
FDR	flight data recorder
FMPI	fluorescent magnetic particle inspection
FOD	foreign object damage
FPI	fluorescent penetrant inspection
FRPC	Flight Data Recorder Playback Centre
hr	hour(s)
HRC	Hardness Rockwell "C"
IFR	instrument flight rules
lat	latitude
lb	pound(s)
long	longitude
N	north
NTSB	National Transportation Safety Board
P&W	Pratt & Whitney
PST	Pacific standard time
SMV	Shop Major Visit
TC	total cycles
TSN	time since new
TT	total time
UHF	ultra-high frequency
UTC	Coordinated Universal Time
VHF	very high frequency
W	west
WAL	Western Air Lines
°	degree(s)
'	minute(s)